Diurnal Patterns in the Persistence of "Thin-Layers" of Marine Snow, Zooplankton, and Turbulent Microstructure in Coastal Waters

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LONG-TERM GOAL

Recent evidence indicates that large detrital aggregates, known as marine snow, are highly concentrated at pycnoclines and other density discontinuities in the water column due to turbulence, shear, and reduced sinking rates as settling aggregates encounter layers of higher density (MacIntyre et al, 1995). The characteristics of these thin layers of high aggregate abundance and their impacts on the distributions of phytoplankton, microbes, and zooplankton in the water column are poorly known, but likely to be significant. Our long-term goal is to develop a predictive understanding of the relationship between the vertical distribution of marine snow, pelagic organisms, and physical properties, including turbulence. Such information will increase our understanding of the patchy distribution of living and detrital matter in the sea and of the impact of thin layers on optical and acoustical properties of the water column.

OBJECTIVES

During 1998, we focused on 4 major objectives: 1) determine the vertical patterns of distribution of marine snow in relation to density stratification and turbulent microstructure in the water column, 2) determine the time scales on which these layers persist 3) examine the significance of physical processes, especially turbulence, in generating or dissipating thin layers of marine snow and 4) relate patterns in the vertical distribution of marine snow and turbulence microstructure to biological, acoustical, and optical properties of the same water column investigated by our collaborators.

APPROACH

In collaboration with a suite of investigators exploring many aspects of the characteristics and formation of thin layers, we measured marine snow, hydrographic properties, and turbulent microstructure, during an intensive three-week field study in June 1998, in East Sound, Washington. East Sound, a shallow fjord in the San Juan Islands, has been studied extensively in the past and provided an ideal site in which to investigate thin-layer formation and persistence. Profiles of turbulent

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kinetic energy dissipation rate (ε), length, and velocity scales of turbulence, and rates of turbulent mixing were obtained to 28 m from a moored platform (R/V Henderson) using a microstructure profiler built by Precision Measurement Engineering. These measurements were made simultaneously with a suite of optical and chemical measurements collected at the same location by Dr. Tim Cowles.

Size distributions and abundances of aggregates larger than 0.5 mm in diameter (marine snow) were determined with an *in situ* still camera and were accompanied by simultaneous measurements of temperature, salinity, and in vivo fluorescence as described in MacIntyre et al (1995). The photographic film was analyzed with computerized image analysis. We also used SCUBA to make direct observations of dye dispersed in the water column and to collect aggregates of marine snow and the organisms attached to them.

WORK COMPLETED

We obtained 470 microstructure profiles and over 30 profiles of marine snow abundance during the 1998 field study, including intensive profiling during 2, 30 hour, diel periods. In the 3 months since the conclusion of the field study, we have analyzed 1/3 of the marine snow profiles and have processed selected microstructure profiles associated with them. In collaboration with other Thin Layers PI's we are focusing on several dates which show particularly interesting patterns in marine snow, acoustical, and optical properties. We are particularly interested in correlations between marine snow abundance and zooplankton abundance measured simultaneously by Van Holiday using acoustic techniques and have been sharing data extensively with the Holiday laboratory.

We have also completed analysis of similar data collected during the 1996 field study in East Sound and are preparing manuscripts from that early pilot study.

RESULTS

East Sound, 1998: Our preliminary analysis indicates that pronounced layering of marine snow occurred persistently just below a strong pycnocline. Turbulent intensity was low ($\varepsilon < 10^{-8} m^2 s^{-3}$). The importance of shear to layer formation was observed by divers when fluorescein dye, introduced over a 1-m vertical layer at 9-10 m depth, was initially tilted and subsequently spread into a thin, horizontal layer. During this time, rates of energy dissipation were less than $10^{-9} m^2 s^{-3}$ indicating little vertical mixing. Layering of marine snow and acoustic scatterers occurred within a pycnocline immediately below a shallow upper mixed layer with moderate levels of turbulence. Our results confirm our previous observations that layers of marine snow are associated with density gradients and moderate to low levels of turbulence.

East Sound, 1996: In 1996 an extremely pronounced 1-m thick thin layer of marine snow two orders of magnitude larger in cumulative volume than concentrations occurring elsewhere in the water column, persisted for at least 24 hours at a depth of about 7 m (see ONR Annual Report, 1997). Completion of the analysis of this data set indicates that this thin layer was consistently associated with an isopycnal of 21.4 kg m^{-3} and a salinity of 28.1 o/oo. This finding confirms our preliminary conclusion that marine snow thin layers can result when mucus containing aggregates attain neutral buoyancy when sinking into water of higher salinity. We have developed a model explaining thin-layer formation based on the resistance of mucus-containing aggregates to salt diffusion, which is fully supported by these field data.

IMPACTS/APPLICATION

Accumulations of marine aggregates in thin-layers is likely to have significant impacts on the optical properties of the water column. Future comparisons of our data with optical data collected simultaneously by Tim Cowles will test this hypothesis. Moreover, thin layers of marine snow are likely to impact the distribution of zooplankton in the water column, ultimately altering the acoustic properties as well. Some zooplankton, including euphausiids and copepods, consume marine snow (Dilling et al., 1998) and may accumulate in marine snow layers. Others may avoid marine snow if their feeding appendages are easily clogged by mucus. Since microorganisms and phytoplankton are common components of marine snow, the distribution of some of these taxa in thin layers may result directly from their association with marine snow. Our coupled biological and physical studies will help determine the role of marine snow in the formation and persistence of thin-layers of various organisms in the water column.

TRANSITIONS

MacIntyre participated in one of P. Franks and J. Jaffe's ONR funded cruises in November 1997. Franks and Jaffe used the Fish TV to look at distributions of plankton. Our microstructure profiles were used to determine the intensity of mixing during their study.

RELATED PROJECTS

The Thin-layers project involves numerous PI's with whom we collaborate. We will be involved in extensive inter-comparisons of our data sets as data analysis of the 1998 field study progresses. Appropriate PI's and projects include:

1 - Van Holiday (Tracor) – We are examining correlations between zooplankton distributions measured acoustically by Holiday and distributions of microstructure and marine snow.

2 - Tim Cowles (Oregon State) – Our temperature-gradient microstructure profilers were on the same instrument package as Cowles' CTD and instruments for measuring attenuation and absorbance (Wetlabs AC-9), fluorescence (SAFIRE), and 3D velocity (ADV). With this concurrently collected data, we will be able to relate the presence and absence of turbulence to water column shear and stratification. In addition, we will be able to determine the rates of energy dissipation and coefficient of eddy diffusivity where thin layers of phytoplankton and DOC are observed. We will learn how long thin layers persist and when they are disrupted by the turbulence in the water column.

3 - Diane Gifford (Rhode Island) – Dr. Gifford is examining the impacts of protozoan grazing on the formation and persistence of thin layers. We have provided her with marine snow samples collected at depths throughout the water column in order to determine if micrograzers are free-living or associated with snow.

4 - Mary-Jane Perry (U. Washington) – We will correlate turbulence and marine snow distributions with distributions of primary production and nutrients obtained by Dr. Perry.

5 - Jan Rines (Rhode Island) – Dr. Rines will be examining marine snow samples for associated phytoplankton. She has already provided us with valuable taxonomic information regarding phytoplankton in East Sound.

6 - Percy Donaghay (Rhode Island) – Extensive information on the physics of East Sound and on the movement of water masses past our study site obtained by Dr. Donaghay will allow more accurate interpretation of our results.

7 - James Case (Santa Barbara) – The marine snow camera and microstructure profiles was deployed simultaneously with an in situ bathyphotometer under development by Dr. Case. The bathyphotometer measures the bioluminescence potential of the water column. We will be correlating results from these profiles and the marine snow camera based on bioluminescence measurements made of individual marine snow samples by graduate student, Christy Herren, who is supported by an ONR AASERT grant.

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